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STRENGTH DISTRIBUTIONS AND POTENTIAL FOR MULTIPLE PILLAR COLLAPSE

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JULY 1985

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STRENGTH DISTRIBUTIONS AND POTENTIAL FOR MULTIPLE PILLAR COLLAPSE

by

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ABSTRACT

Initiation of prolonged rockburst activity in mined-out workings at the Quirke Mine, Elliot Lake dates from March 1982. Since then considerable effort has been made to document the visible signs of its progress. Photographs have been taken, convergence has been measured between roof and floor, and microseismic systems have located burst sources. The complex room-and-pillar geometry has been the subject of various attempts to model numerically the failure states of pillars.

A detailed survey based upon existing stope plans of 327 pillars was made in an area centred on the so-called trackless zone and extending out approximately 300 m in radius. The data, arranged as strength distribution (frequency) functions, is used to calculate probabilities of spontaneous collapse under a variety of assumed conditions.

Photographic evidence suggestive of violent failure in designated zones and/or pillar types is examined in detail.

Of all pillar types represented in the study zone at the Quirke Mine, sill pillars are the least likely and canted pillars the most likely to fail in a spontaneous collapse. Taking the overall pillar data base as an example, extraction ratio should, in theory, decrease with depth by as much as 6% per 100 m to maintain an even probability of spontaneous collapse.

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RÉPARTITION DE LA RÉSISTANCE DANS LES PILIERS ET POSSIBILITÉ D'EFFONDREMENT MULTIPLE

par

G. Swan*

RÉSUMÉ

Le déclenchement d'une activité prolongée de coups de toit dans les travaux abandonnées de la mine Quirke à Elliot Lake, s'est produit en mars 1982. Depuis lors, on a fait des efforts considérables pour relever les signes évidents de la progression de cette activité. On a photographié les lieux et mesuré la fermeture entre le toit et le plancher et utilisé des systèmes microséismiques pour repérer les sources de coups de toit. La géométrie complexe du toit et des piliers a été soumise à des essais de modélisation numérique variés visant à évaluer l'état de détérioration des piliers.

Une étude détaillée, basée sur les plans actuels de 327 piliers a été effectuée dans une région dont le centre consiste en une zone "vague" couvrant un rayon d'approximativement 300 m. Les données, qui ont été classées d'après les fonctions (fréquence) de répartition de la résistance sont utilisées pour calculer les probabilités d'un effondrement spontané dans diverses conditions hypothétiques.

La documentation photographique qui permet d'observer les indices de détérioration violente dans les zones désignées et dans les piliers-types fait l'objet d'un examen détaillé.

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De tous les types de piliers représentés dans la zone à l'étude à la mine Quirke, les piliers de fondation sont les moins sujets à la détérioration lors d'un effondrement spontané et les piliers inclinés sont ceux qui le sont le plus. En se fondant sur l'ensemble des données de la base de données, théoriquement, le taux d'extraction devrait décroître, d'au moins 6 % par 100 m , selon la profondeur, afin qu'il soit possible de maintenir une courbe de probabilité uniforme quant à l'éventualité d'un effondrement spontané.

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INTRODUCTION

Initiation of prolonged rockburst activity in mined-out workings at the Quirke Mine, Elliot Lake dates from March, 1982. Since then considerable effort has been made to document the visible signs of its progress (1). Photographs have been taken, convergence has been measured between roof and floor, and microseismic systems have located burst sources. The complex room-and-pillar geometry has been the subject of various attempts to model numerically the failure states of pillars. Such models typically present factors of safety for discrete zones rather than actual pillars. Furthermore, pillar strengths used are generalizations which avoid assigning individual pillar strengths. In order to investigate a multiple collapse situation such models would require numerous reruns at considerable expense.

Recent work on multiple-pillar failure modes (2) applied a simple statistical model to the rib pillar configuration in Denison Mine. The results showed a potential for application in the adjacent Quirke Mine where pillar geometries, and thereby strengths, have a much broader variation. Thus, at Quirke, pillar width:height (w/h) ratios range from 0.60 to 1.25 compared with a local value of 1.27 for Denison (2). This report documents the results from a detailed survey of 327 pillars from existing mine plans in an area centred on the so-called trackless zone and extending out approximately 300 m in radius. The data, arranged as strength distribution (frequency) functions, is used to calculate probabilities of spontaneous collapse under a variety of assumed conditions.

PILLAR STRENGTH SURVEY

Observations of rockbursts at the Quirke Mine have confirmed that an affected area is spreading out from the so-called trackless zone, (zone 1) see Figure 1. Pillars within the affected area (here arbitrarily limited to three

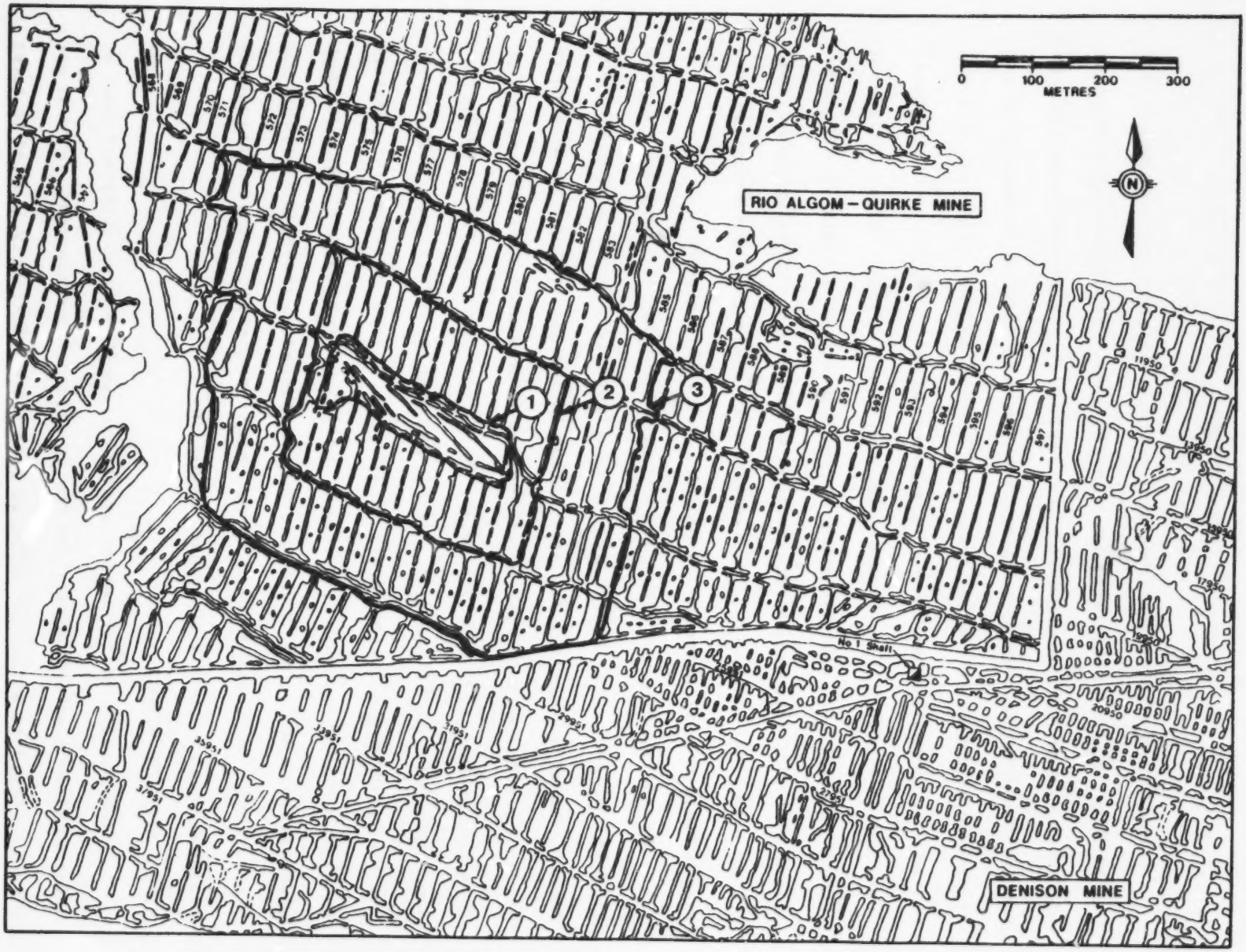


Fig. 1 - Details of room-and-pillar layout as developed at the Quirke Mine, 1984.

zones) comprise a mixture of canted (apparent dip) rib, crown and sill pillars. From a strength point-of-view these terms are significant only in that they characterize pillar w/h ratios. The crowns and sills are typically "squat" with w/h $\geq$ 1 compared to ribs which are "slender", w/h = 0.65. A survey of all pillars within the zone 3 boundary, Figure 1, gave the variations of (w/h) by pillar type summarized in Table 1.

Table 1 - Summarized Pillar w/h Statistics

Pillar Type	Number Surveyed	w/h	
		Mean	S.Dev.
Normal Rib	201	0.72	0.39
Canted Rib	11	0.59	0.11
Sill	59	1.25	0.45
Crown	56	0.93	0.37

For the Elliot Lake mines it is considered that in situ pillar strength can be obtained empirically from (3):

$$Q = 133\ w^{0.50}/h^{0.75} \qquad (1)$$

Units here are in MPa and metres. Since the orebody is dipping at approximately 20 degrees the loaded and geometric width will differ significantly for all but rib pillars. A correction can be made through

$$w = w_g/\cos a - h\tan a \qquad (2)$$

where a is the local dip angle and w_g is the geometric width. Furthermore, since equation (1) is valid for rectangular pillars, L/w = 20:1, a correction should also be applied to account for the general case of L $\neq$ 20w. However, only a few random pillars with L << 20w exist in Quirke Mine and these have a negligible role upon stability. Therefore, an "effective" pillar width (see

(4)). given in this case by

$$w_e = 21wL/[20(w + L)] \quad (3)$$

is noted here for reference, but not applied.

From the pillar survey and an application of equations (1) and (2) eight frequency polygons for strength were calculated. These were based upon two categories of pillar classification; zonal and geometrical. In the first, all pillars within each of the zone boundaries 1, 2 and 3, Figure 1, were examined. The zones are not considered to overlap. This category also includes a polygon for all pillars, zones 1+2+3. In the second, the pillar identities normal rib, canted rib, sill and crown are used to differentiate geometries common to the mine. As noted above, random pillars also exist in the mine but these will have a minor role given a collapse situation.

Strength statistics for each sub-category are provided in Table 2. All eight frequency polygons are plotted in Appendix A, Figures A1-A8.

Table 2 - Summarized pillar strength statistics

Pillar Sub-Category	Number Surveyed	Compressive Strength (MPa) Mean	S. Dev.	Coefficient Variation %
Zone 1	31	56.6	15.5	27.4
Zone 2	83	68.5	15.9	23.2
Zone 3	213	81.1	25.4	31.3
Overall	327	75.5	24.0	31.8
Normal Rib	201	75.8	21.3	28.1
Canted Rib	11	49.4	12.2	24.7
Sill	59	86.1	28.0	32.5
Crown	56	68.7	25.1	36.5

PROBABILITY MODEL FOR COLLAPSE

In an ideal situation of parallel pillars, for which the total load is always distributed equally, a probabilistic model can be devised. Such a model was applied recently to Denison Mines on a limited basis. The model

accounts for spatial peak strength variability and includes post-failure or residual strength effects. Since the details of in situ pillar loading are not available, the assumption of an even load distribution is unavoidable but restrictive. It will, for example, preclude the modelling of abutment effects. As a first step towards probabilistic modelling it is therefore conservative in assessing a collapse potential.

Taking the frequency polygons of each pillar sub-category, three hypothetical scenarios were considered. These were, for each sub-category:

a) 20 pillars collapse spontaneously, with no post-failure strength development;

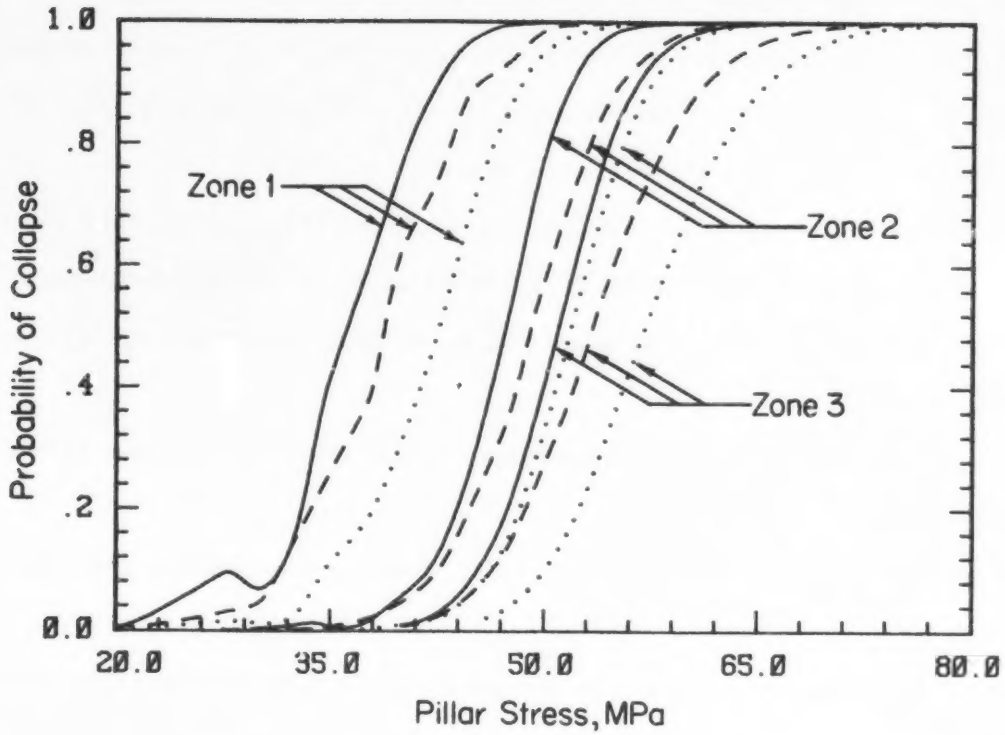
b) 10 pillars collapse spontaneously, with no post-failure strength development;

c) 10 pillars collapse spontaneously, all of which develop 50% post-failure strength.

The model described in (2) can then be used to calculate probabilities for the occurrence of 1, 2 and 3 as functions of stress.

Results for each of the zones 1, 2 and 3 are plotted in Figure 2. The overall or summed zone result appears in Figure 3. For the geometrical category, paired results for the crown/sill and normal/canted rib pillars are shown in Figures 4 and 5 respectively.

Following Swan (2) the stress giving an even chance of spontaneous collapse can now be used to suggest an upper limit for the extraction ratio, R. In doing this it is appropriate to account for dip angle in calculating S_o of 10.5 MPa to 14.0 MPa respectively. These two values were used to calculate R, obtaining the results for all pillar sub-categories shown in Table 3, and Figure 6.

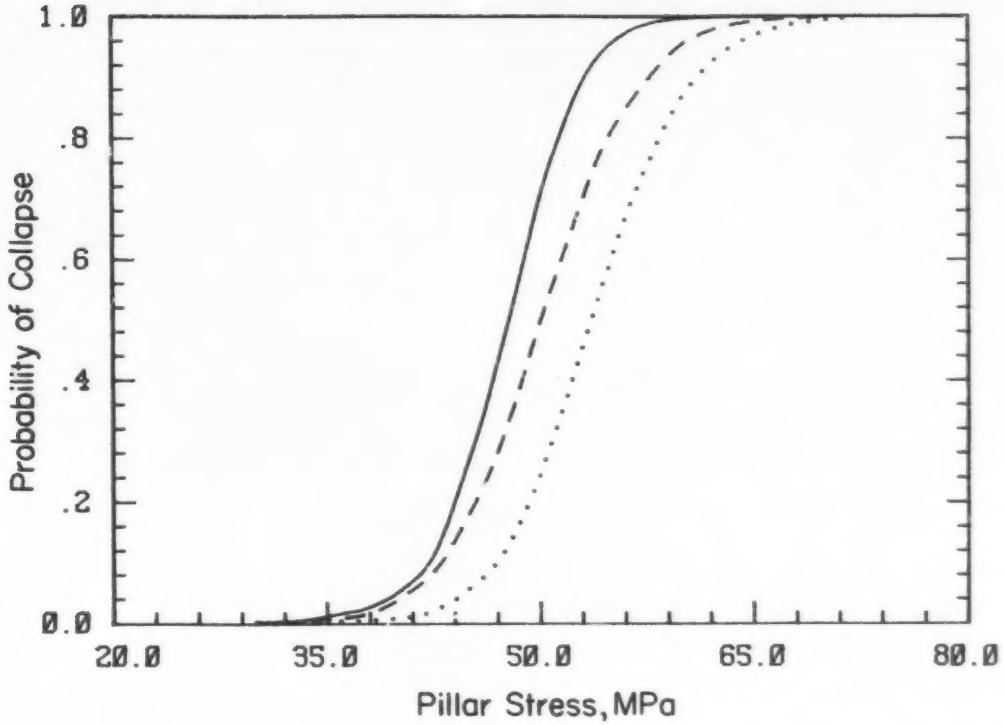


——— 20 pillars, no post-failure

------ 10 pillars, no post-failure

..... 10 pillars, 50% post-failure

Fig. 2 - Probability of spontaneous collapse in three zones of pillar types at Quirke Mine.

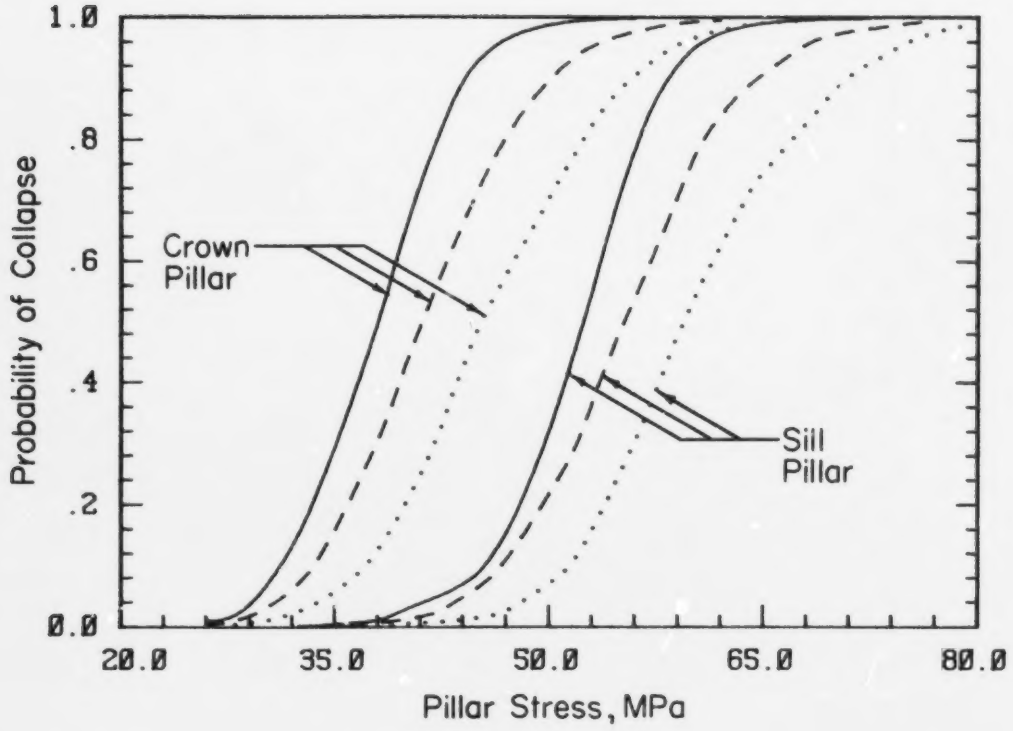


—— 20 pillars, no post-failure

---- 10 pillars, no post-failure

.... 10 pillars, 50% post-failure

Fig. 3 - Probability of spontaneous collapse based upon aggregate pillar statistics from all three zones, Quirke Mine.

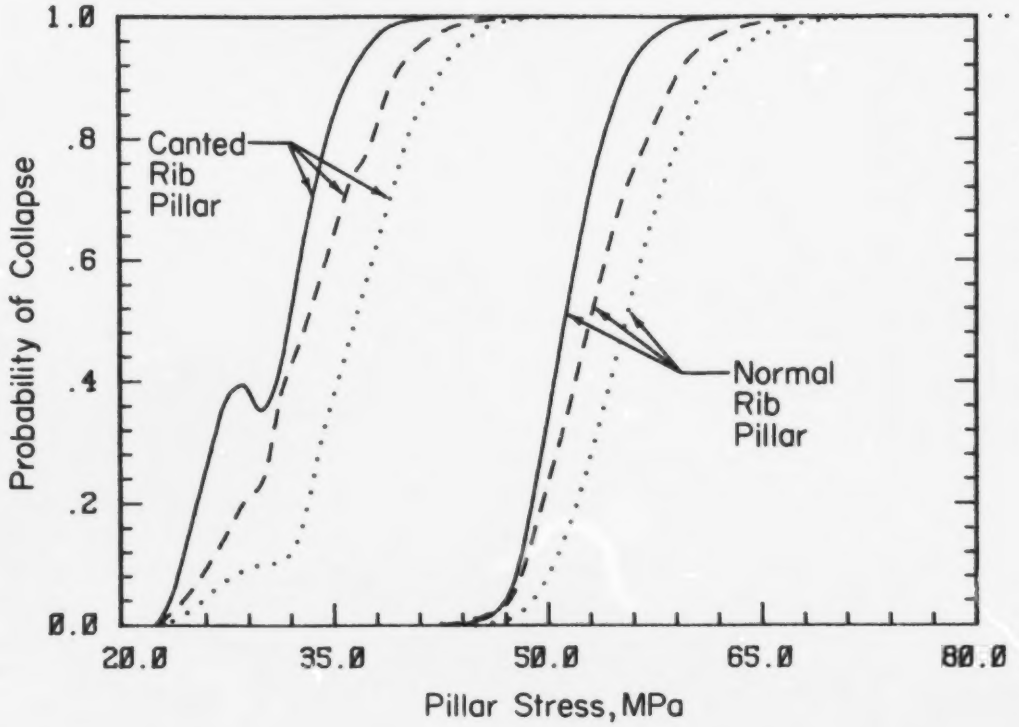


—— 20 pillars, no post-failure

---- 10 pillars, no post-failure

.... 10 pillars, 50% post-failure

Fig. 4 - Probability of spontaneous collapse in crown and sill pillars at Quirke Mine.

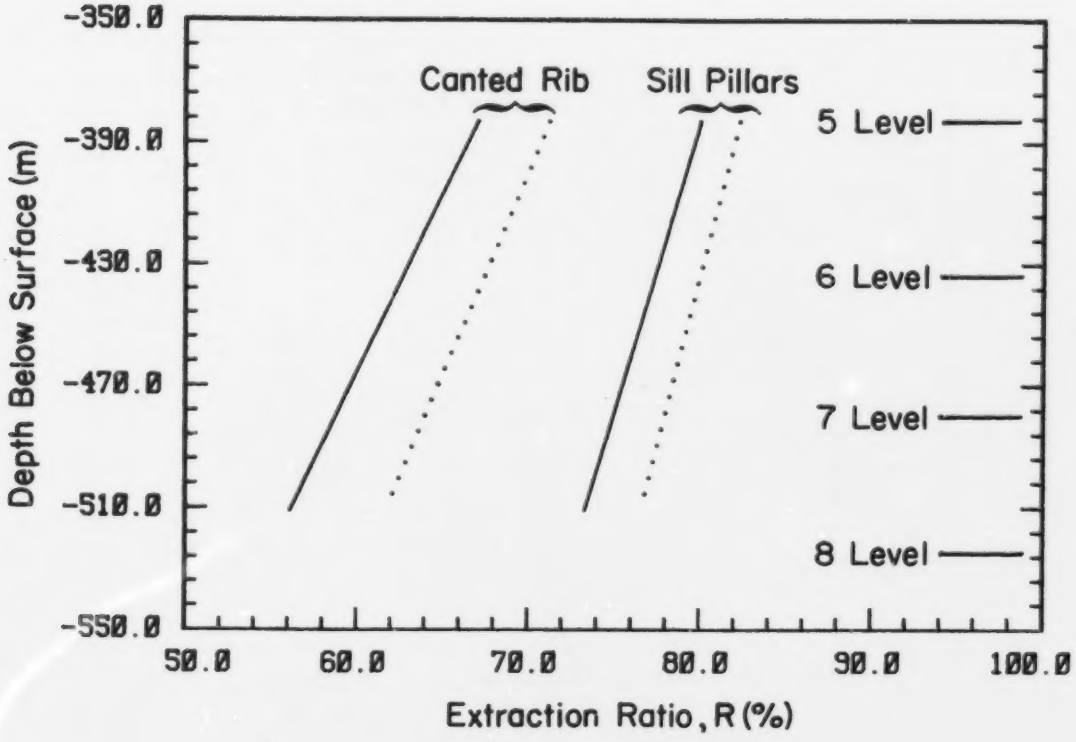


—— 20 pillars, no post-failure

---- 10 pillars, no post-failure

.... 10 pillars, 50% post-failure

Fig. 5 - Probability of spontaneous collapse in normal and canted rib pillars at Quirke Mine.



—— 20 pillars, no post-failure

.... 10 pillars, 50% post-failure

Fig. 6 - Extraction ratios giving an even chance of spontaneous collapse as a function of depth, Quirke Mine.

Table 3 - Extraction ratios giving an even chance of spontaneous collapse for three collapse scenarios (see text).

Pillar Sub-Category	Depth = 383 m, S_o = 10.5 MPa			Depth = 511 m, S_o = 14.0 MPa		
	a	b	c	a	b	c
Z1	70.9	72.9	75.3	61.2	63.9	67.1
Z2	77.8	78.6	79.7	70.4	71.4	73.0
Z3	79.4	80.3	81.6	72.5	73.7	75.4
Overall	78.0	79.0	80.4	70.7	72.0	73.8
Normal Rib	79.5	80.1	81.1	72.6	73.5	74.7
Canted Rib	67.1	68.3	71.2	56.1	57.7	61.6
Sill	80.0	81.0	82.3	73.3	74.6	76.4
Crown	72.3	74.4	76.8	63.1	65.9	69.0

VIOLENT FAILURE - IN SITU EVIDENCE

The term spontaneous collapse is used above to describe an extreme case of multiple pillar failure. Obviously, this will tend to occur with mounting violence since the mine stiffness decreases for each successive failure and an essentially "dead weight" loading system is driving the roof. This being the case, those pillar types experiencing the most violent failures - rockbursts - are likely to have a crucial role in triggering such spontaneous collapses. A close examination of rockbursts in the Quirke Mine with respect to the zonal schemes adopted here is beyond the scope of this report. A detailed survey is, however, under preparation (Hedley (5)). Instead, photographic evidence for violent failures confined to certain pillar geometries is now presented.

In selecting the evidence it is not always possible to be objective; appearances can be deceptive. Violent failure, like "rockburst", is a term open to interpretation. A good indication of violence is seen in the "throw" that a fragment experiences. To appreciate this in a photograph a wide angle lens is imperative. Furthermore, because of the danger of entering areas with a history of violent instability, remote camera work is necessary. Unfortunately, neither of these factors have been exploited to date at Quirke

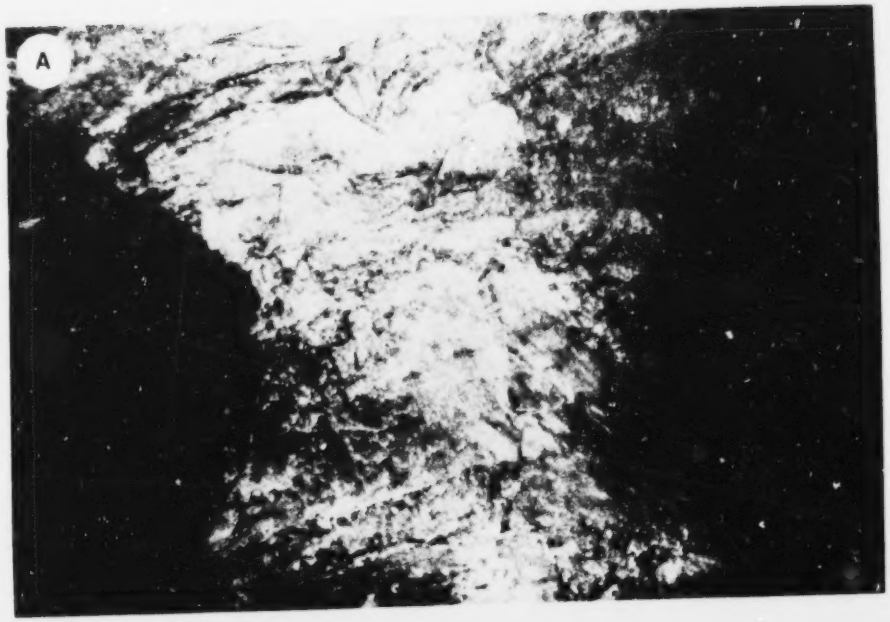
Mine which severely limits the scope of such observations. Taking note of this, some appropriate comments will now be appended to the selected photographs, Figure 7-11. All photographs were taken after a series of rockbursts had occurred during March 1982 (1).

Obviously, in a mine the size of Quirke there will always be some pillars which survive the impact of rockbursts. In the particular case being examined, pillars within zone 3 and beyond fall into this category. Figure 7 shows little or no evidence of failure, even in a small random pillar, Figure 7A. Observations from zone 1 provided examples of increased failure activity with contained violence, Figure 8. The sill pillar, Figure 8B, is bisected with a shallow-dipping thrust fault and yet remains essentially intact. Evidence for spalling and failures of mounting violence can be seen in Figure 9. All three examples are taken from sill pillars on 8 level, zone 2. The evidence for contained violence appeared extensively in zone 1, examples of which are shown in Figure 10. Finally some clear cases of violent failure can be seen in Figure 11.

DISCUSSION

It is clear from the above that theoretical models and visual assessments of collapse are not easily reconciled. As is usual with the complex geometrical and geological configurations which ultimately comprise a mine, assumptions all too readily oversimplify reality. However, it is the very existence of these complexities which probably serves to reduce the probability of spontaneous collapse. Non-uniform stress states, irregular pillar geometries, mixed geological conditions are examples of such stabilizing factors.

With these shortcomings of the statistical model in mind, probabilities of pillar collapse should be viewed in relative terms. As a basis for further



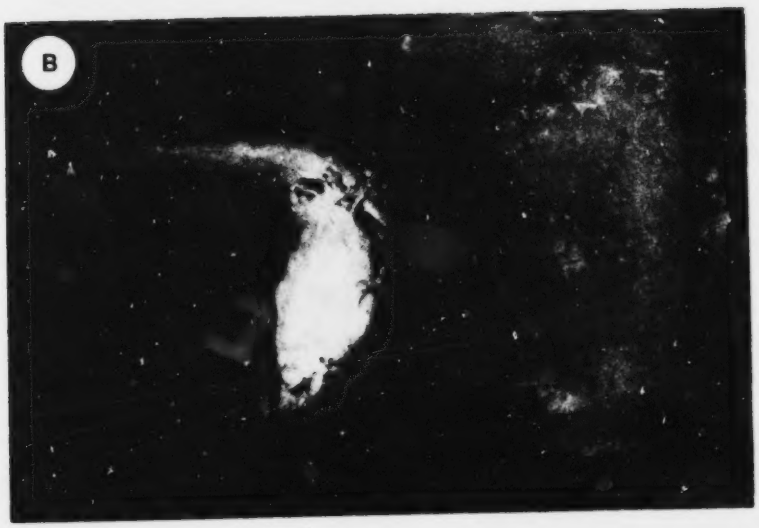


Fig. 7 - Pillars showing little or no evidence of failure, Zone 3.

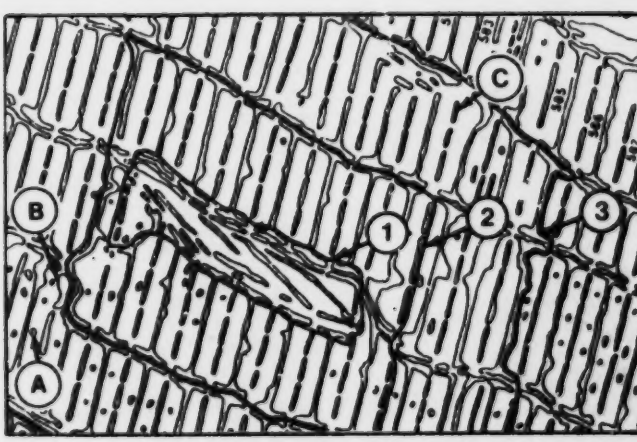
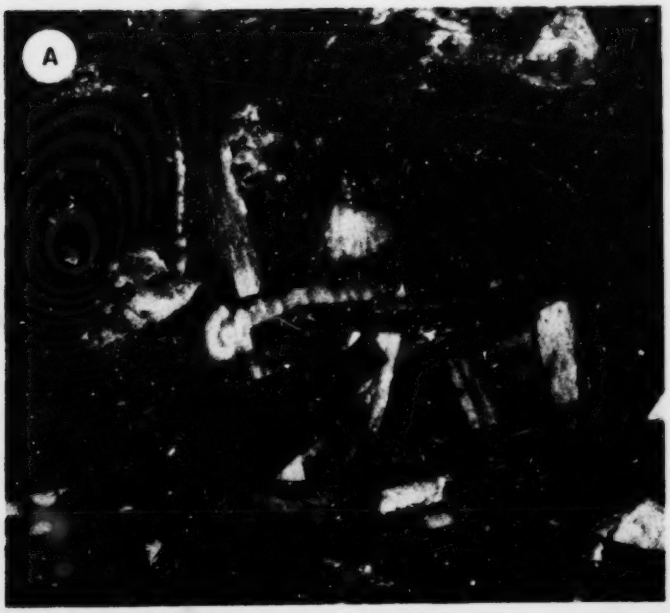


Fig. 8 - Pillars showing evidence of spalling and stable failure, Zone 1.



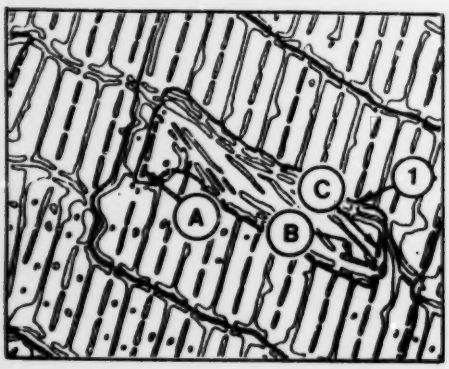
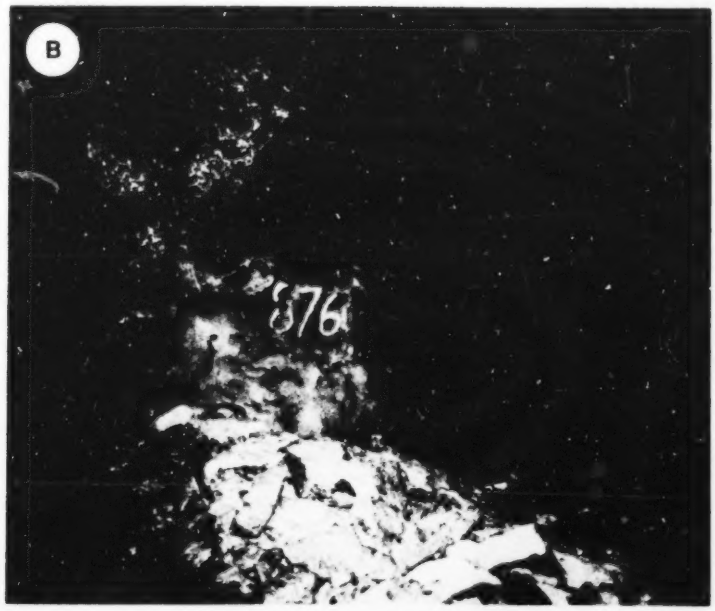
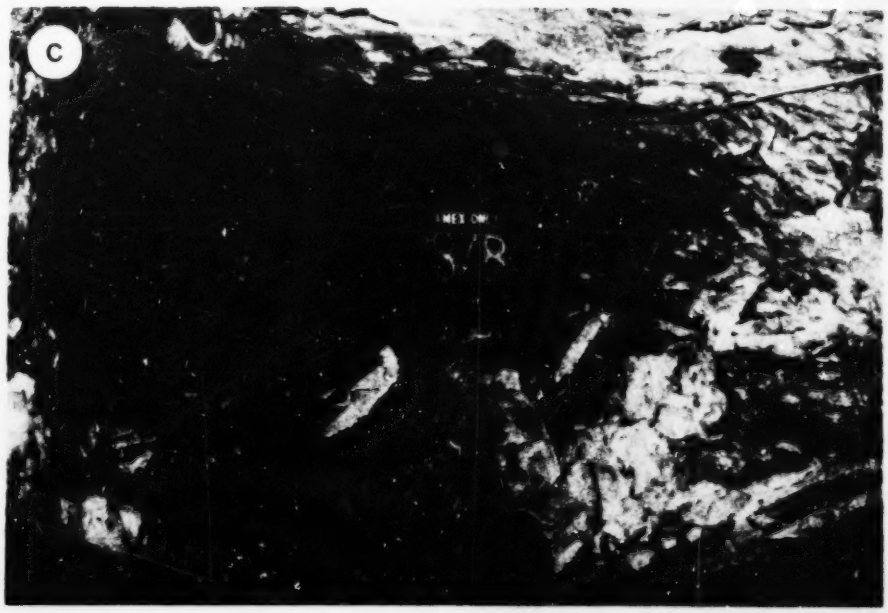
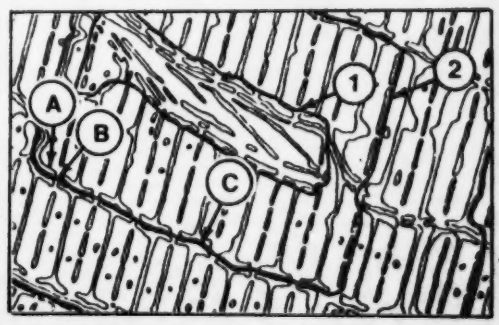
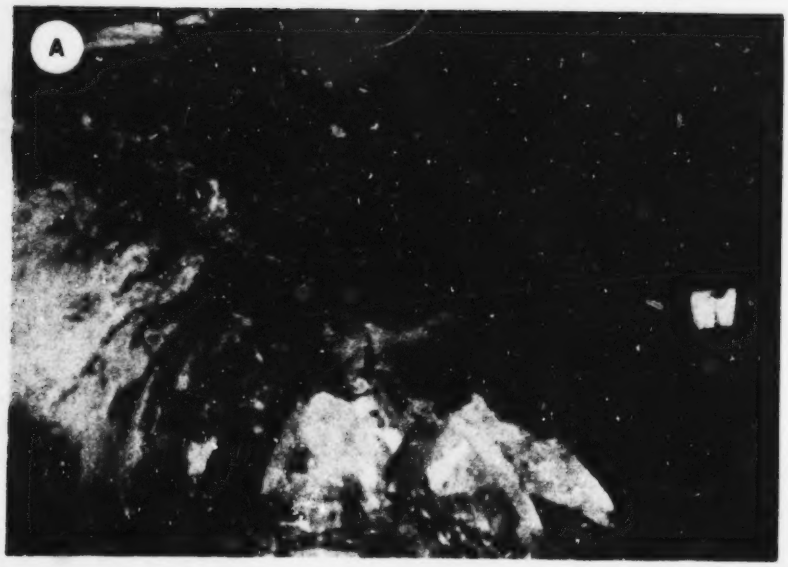


Fig. 9 - Pillars showing some spalling and violent failure, 8 Level, Zone 2.









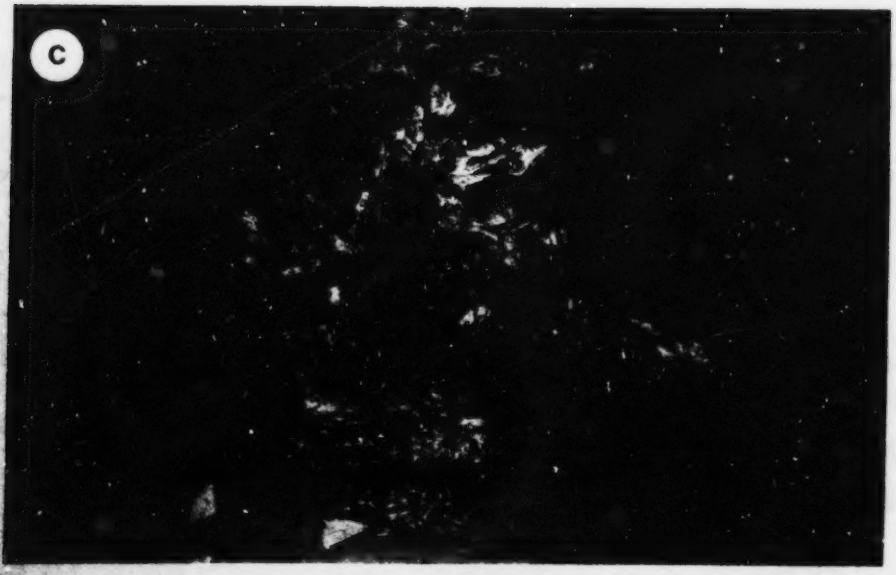


Fig. 10 - Pillars showing evidence of a failure mode in which the violence is somewhat contained, Zone 1.

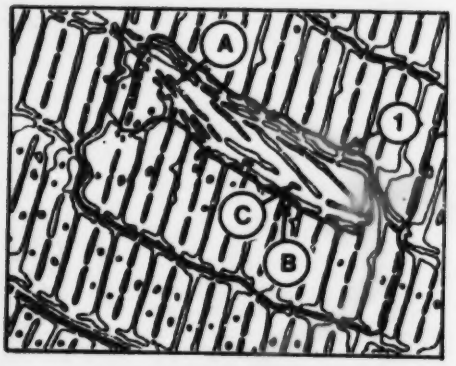
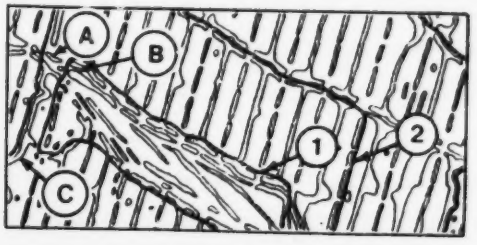
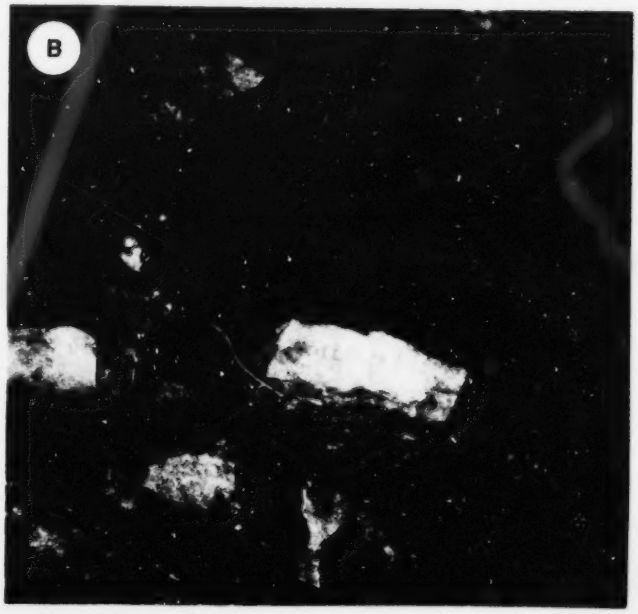


Fig. 11 - Violent failure in pillars of western flank, Zones 1 and 2.





discussion and research in this field the following comments are offered:

a) of all pillar types represented at the Quirke Mine, zones 1-3, Figure 1, sill pillars are the least likely and canted pillars the most likely to fail in a spontaneous collapse;

b) rib pillars, for which geometrical effects due to dip considerations are absent, represent the pillar group whose strength distribution is known with greatest certainty;

c) taking the overall pillar data base as an example, extraction ratio should, in theory, decrease with depth by as much as 6% per 100 m to maintain an even probability of spontaneous collapse.

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APPENDIX A

Frequency polygons of expected pillar strength for eight classes of pillar

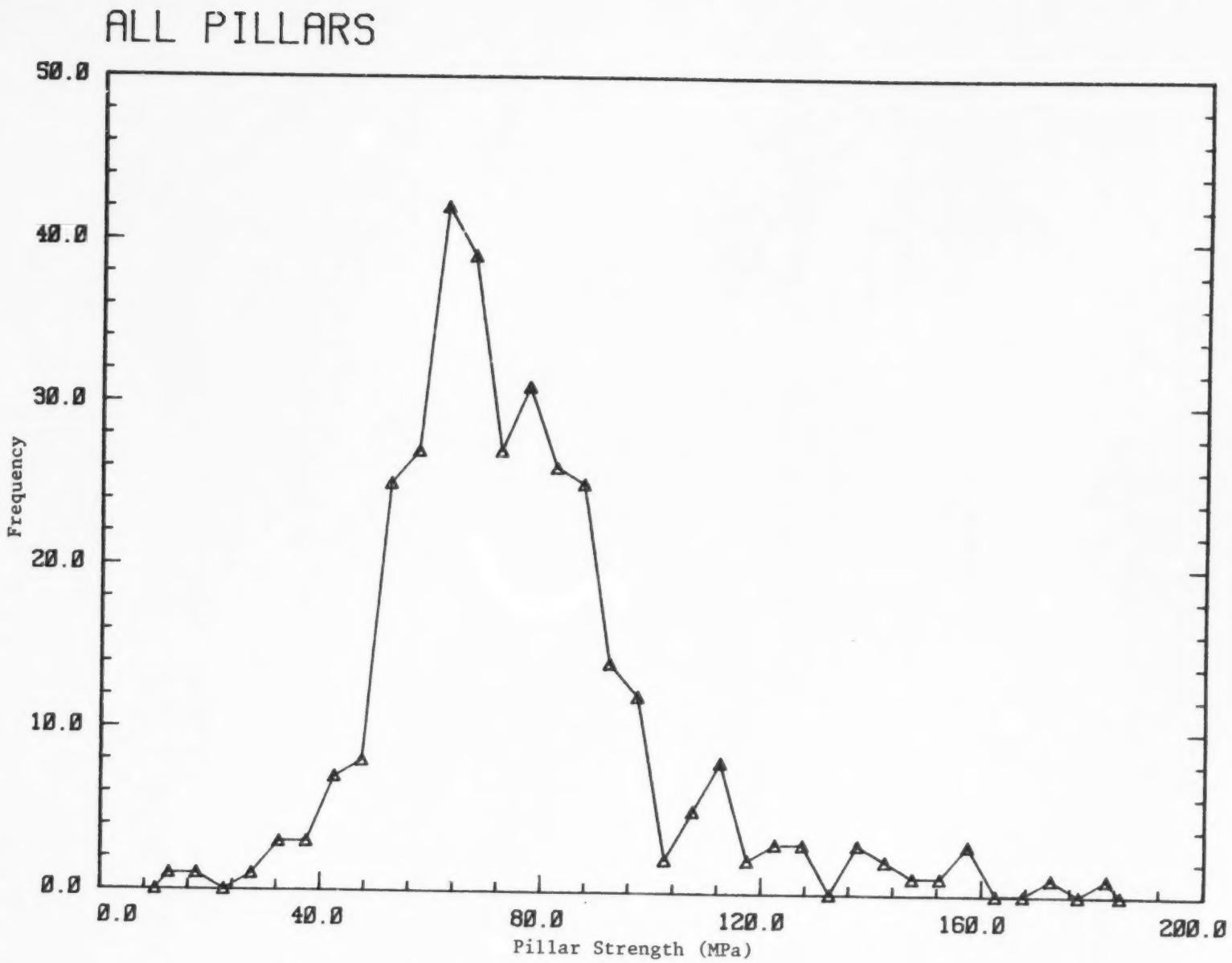

Fig. A-1 - Overall pillars - all pillars in zones 1, 2 and 3.

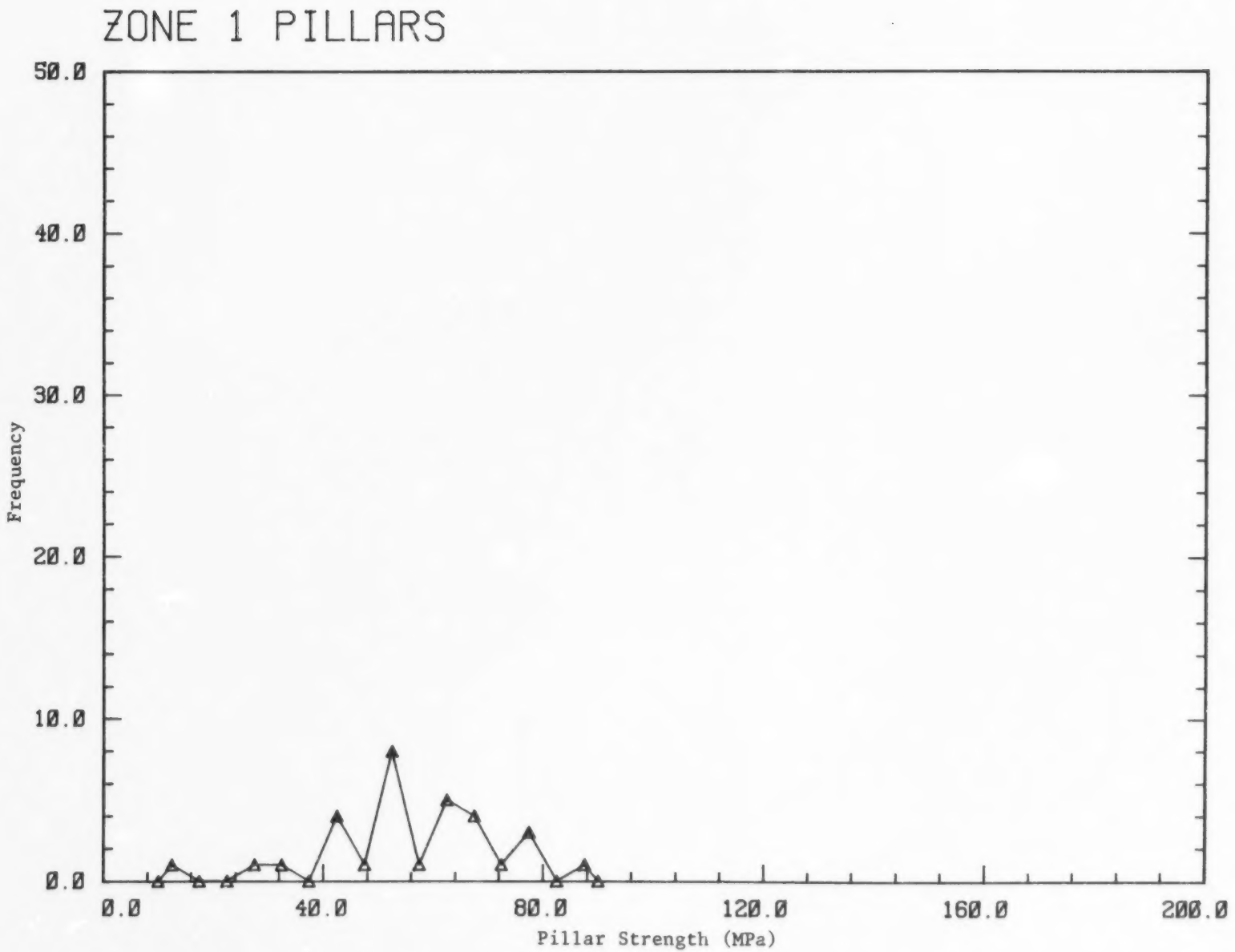

Fig. A-2 - Zone 1 pillars.

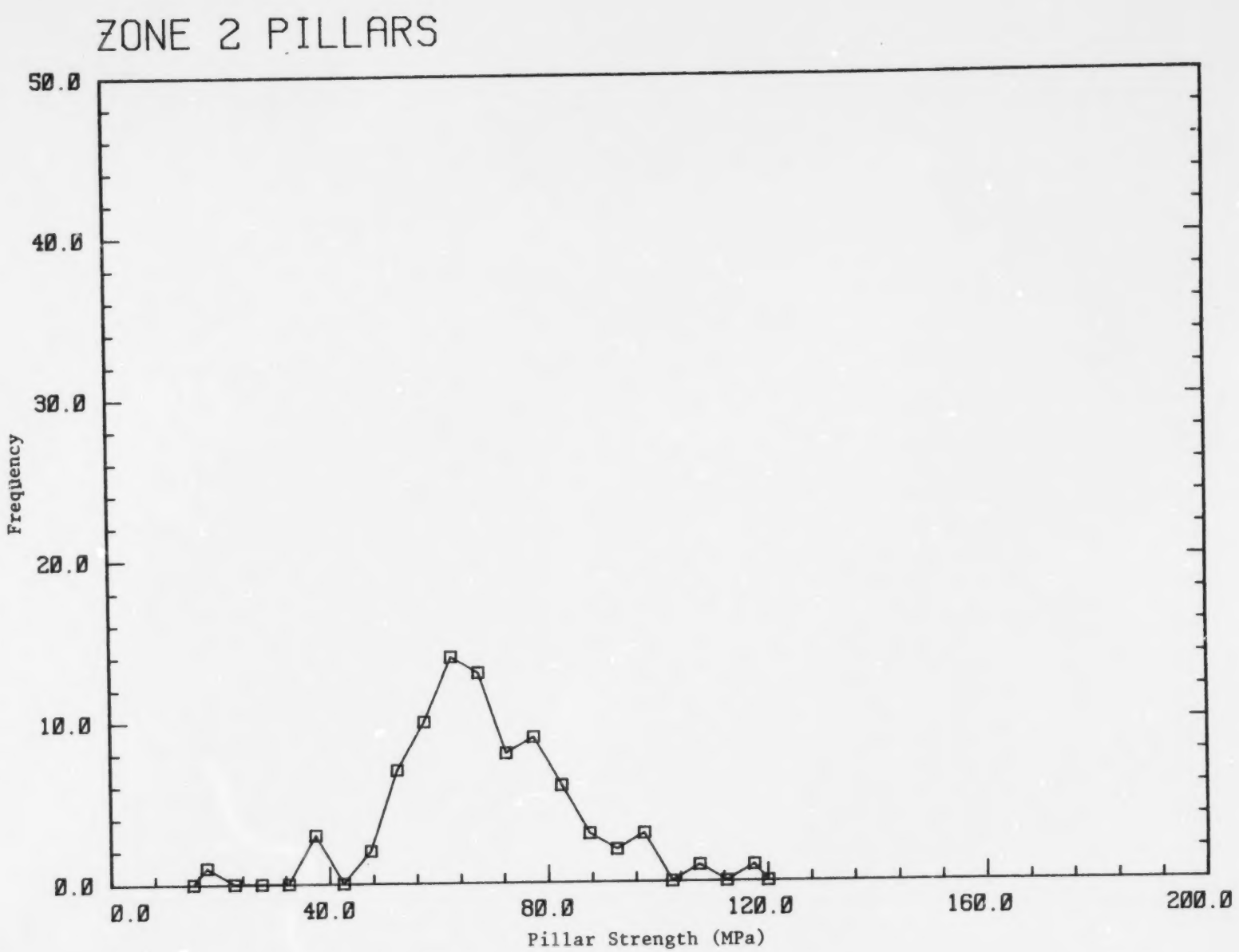

Fig. A-3 - Zone 2 pillars.

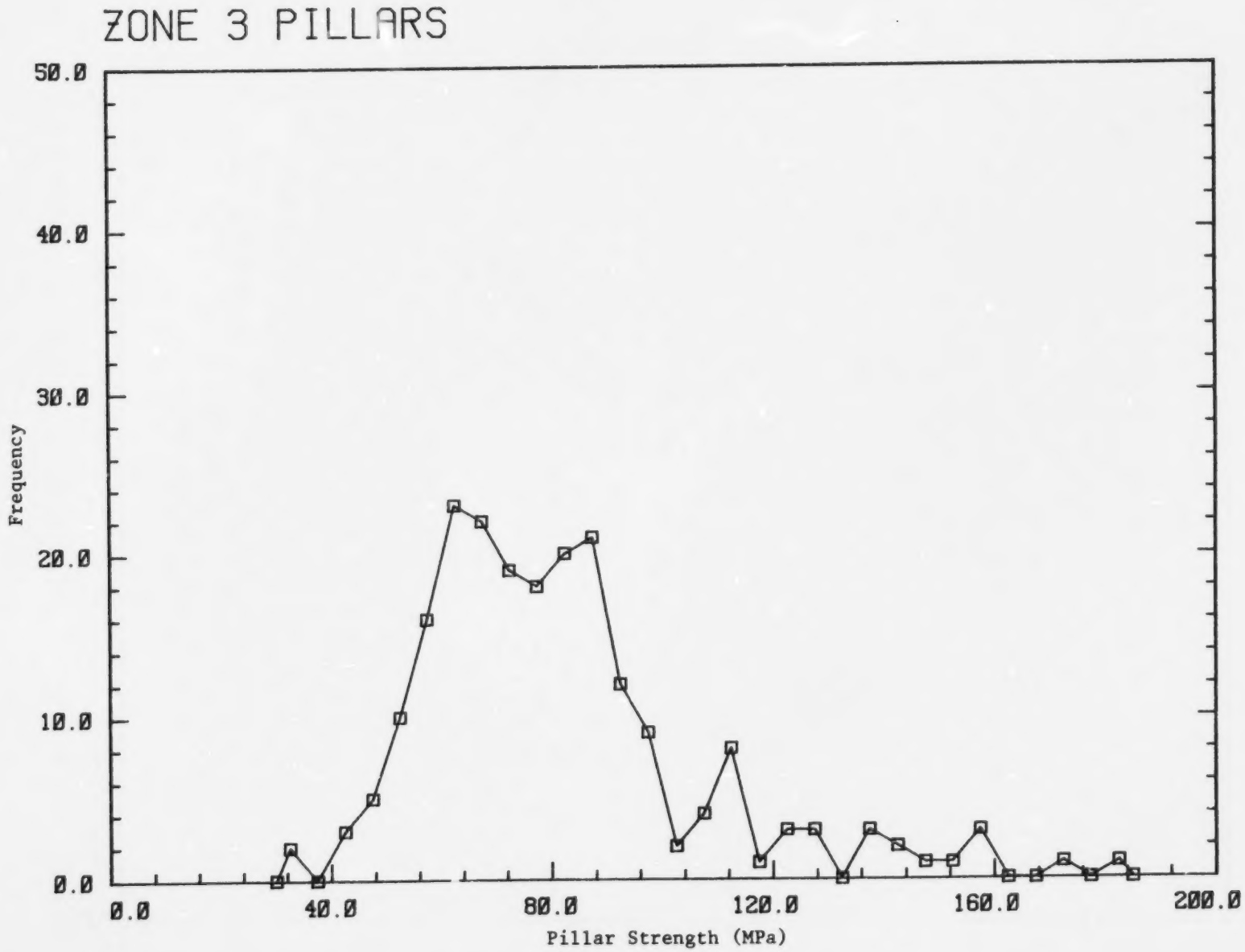

Fig. A-4 - Zone 3 pillars.

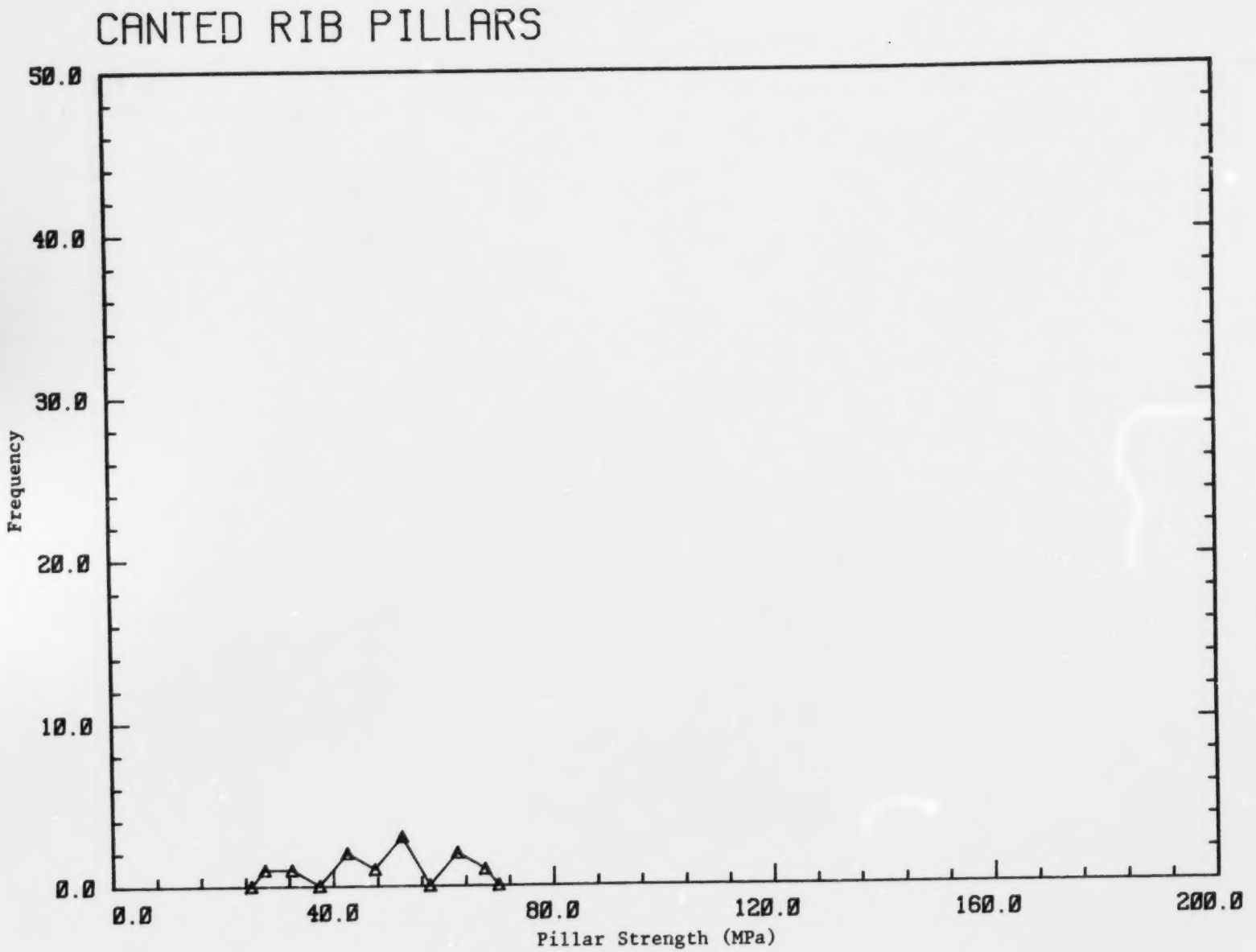

Fig. A-5 - Canted rib pillars.

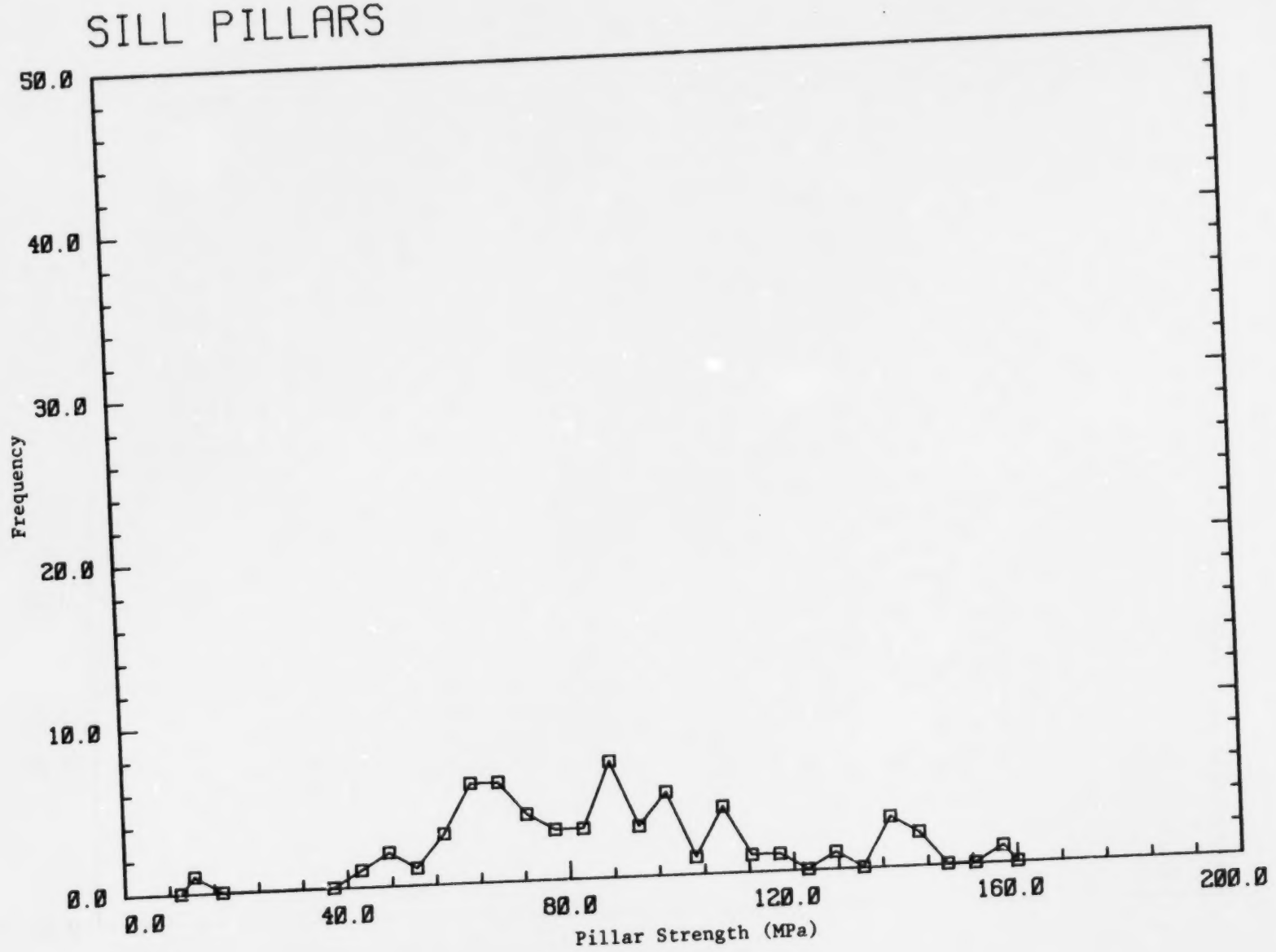

Fig. A-6 - Sill pillars.

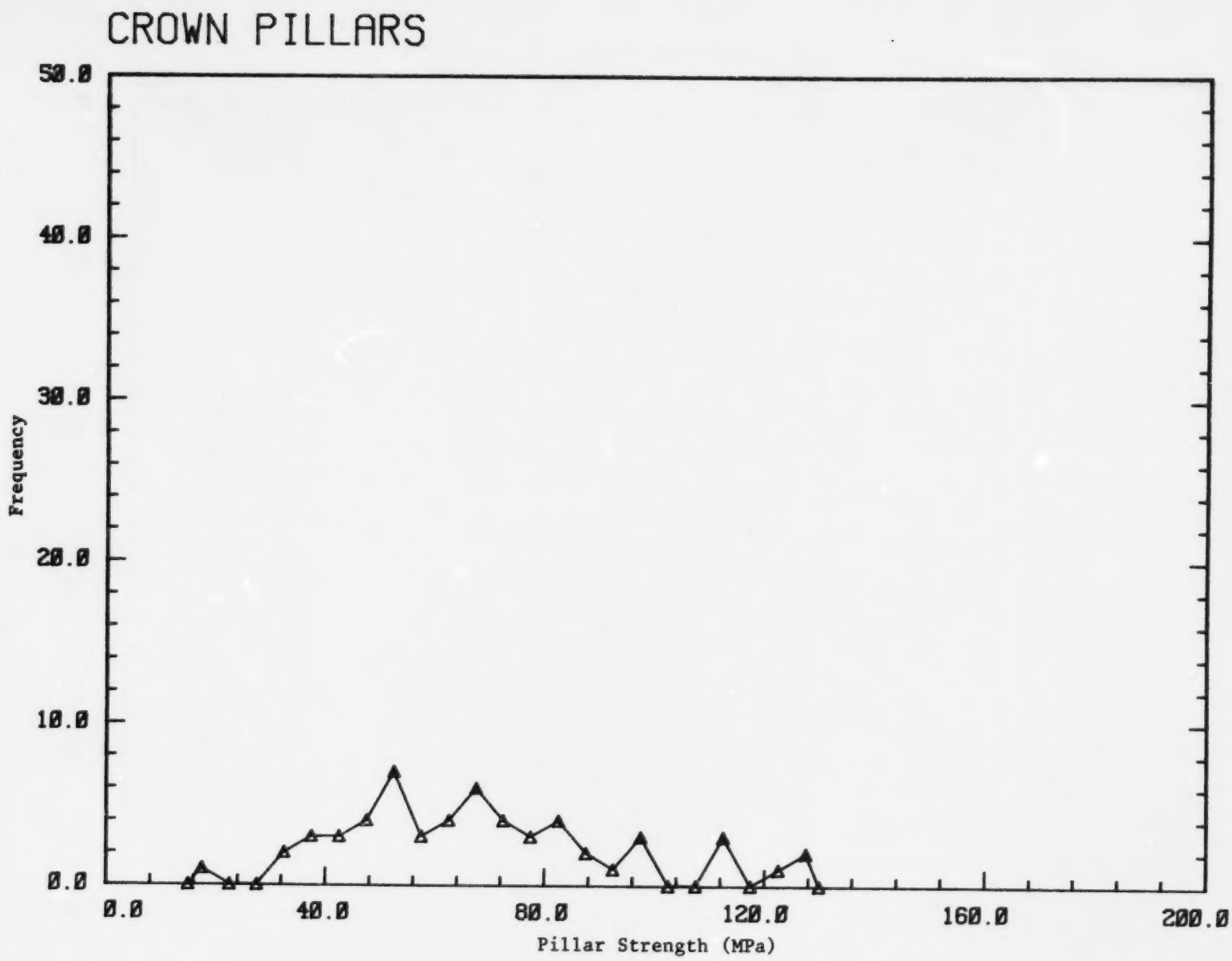

Fig. A-7 - Crown pillars.

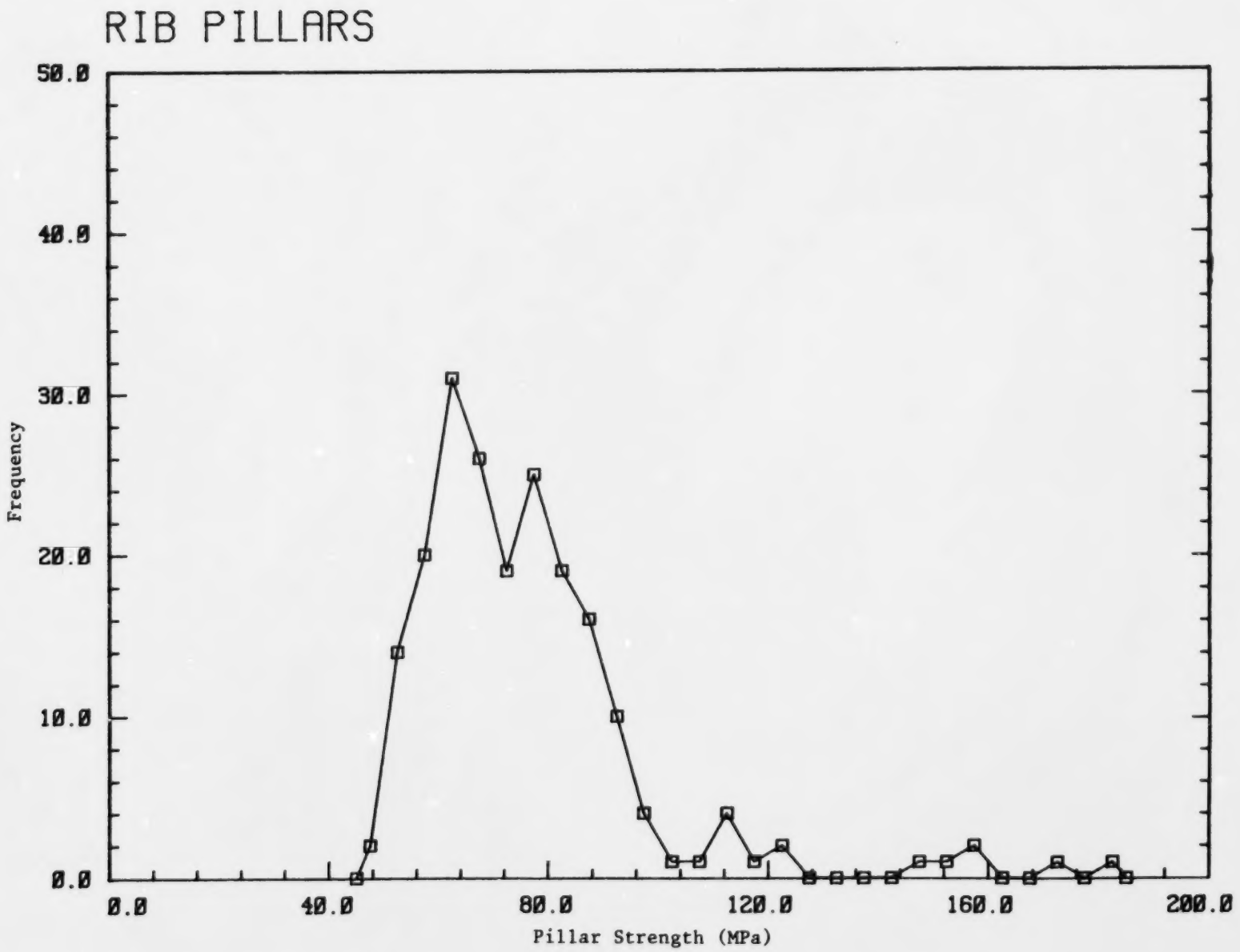

Fig. A-8 - Rib pillars.